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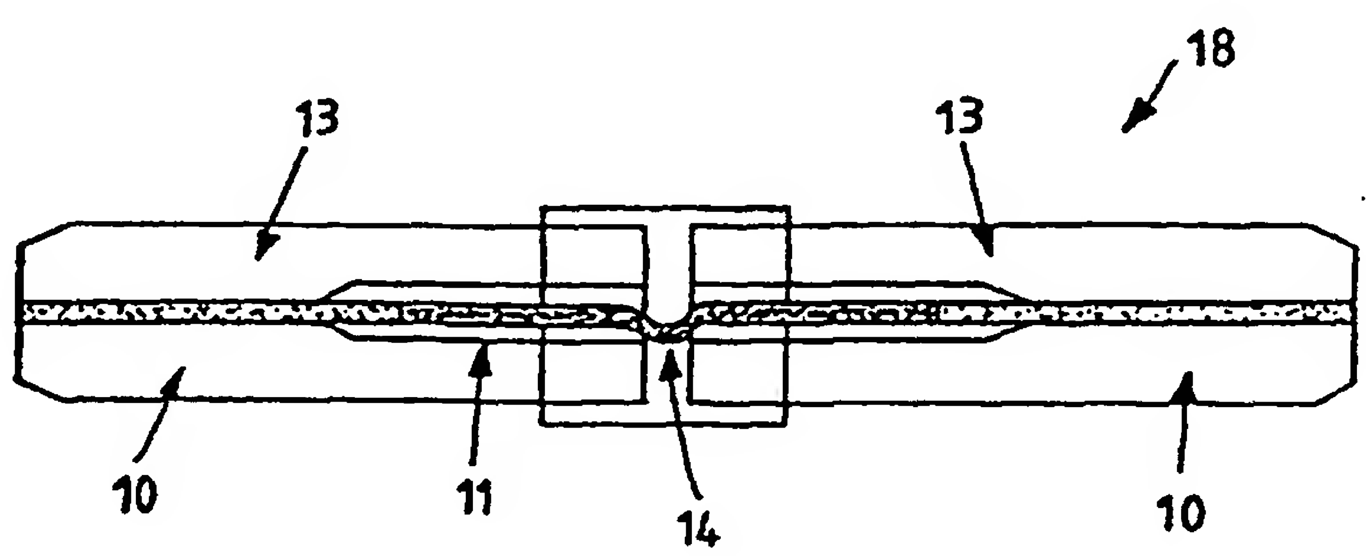


(57) Abstract

Attenuating fibre (11), cut to an appropriate length to yield the desired attenuation valve, is fusion spliced to single mode optical fibre (10) to produce an optical fibre attenuator having low modal interference. The use of doped attenuating fibre and bending this fibre (14) gives a uniform spectral response of the attenuation.

OPTICAL FIBRE ATTENUATORS ASSEMBLED USING ATTENUATING FIBRE

The present invention concerns a process for the realization of attenuating elements for optical fibres with attenuating fibre.

At present, optical all-fibre attenuating elements, with spectral response independent from the wave length, are mainly realized making use of a particular technique of deformation of the core of an optical fibre.

However, said method allows to obtain a minimum independence degree of the attenuation from the wave length which, as such, would be desirable to be increased; furthermore, experience shows that a determined residual dependence of the spectral response from the connection quality reamains, especially in the attenuating elements based on the use of an optical fibre with a standard deformation.

The reason is to be found in the modal interference existing between the two connection and the central attenuating area which - even if the methods suggested until now are able to reduce the effect thereof - still holds on, bringing about a determined variability of the attenuation with the wave length and a substantial reduction of said attenuation, with respect to the nominal value, when the attenuating element is directly installed in front of the receiver.

Therefore, it is the aim of the present invention to obviate above mentioned inconveniences, in particular to show a new process for the realization of compact attenuating elements for optical fibres, based on the use of attenuating fibre with a response independent from the wave length, and that therefore allows to reduce the modal interference that arises therein, with respect to the conventional techniques.

It is a further aim of the present invention to show a process for the realization of attentuating elements for optical fibres with an attenuating fibre, which allows to obtain a spectral response idependent from the wave length, even with high wave lengths, where usually the monitoring of telecommunication network is performed.

Another aim of the present invention is to realize a compact attenuating element for optical fibres, with a response independent from the wave length, according to the process claimed by the present invention.

Still another aim of the present invention is the one of showing a process for the realization of attenuating elements for optical fibres with attenuating fibre at substantially moderate costs, without making use of complex or expensive technologies.

Said aims set forth are reached according to the present invention by means of a process for the realization of attenuating elements for optical fibres with attenuating fibre, according to claim 1, and by means of an attenuating element for optical fibres with attenuating fibre, according to claim 4.

The suggested method is based on the use of an optical fibre with high intrinsic attenuation and with geometric features similar to those of a standard monomodal optical fibre.

The optical attenuating element realized according to this method can reduce in drastic manner the modal interference that arises therein and all further negative consequence of a conventional process.

A controlled stress on the central area of the attenuating fibre or of the standard fibre, consisting of a light bending of said fibres, is introduced with the purpose of improving the spectral response of the attenuating element with high wave lengths; the stress determines an increase of attenuation at high wave lengths, thus counterbalancing the rough reduction of the spectral attenuation of the fibre, attenuated in this area.

This allows to make the spectral response of the attenuating element further flat, also towards greater wave lengths, where usually the monitoring of telecommunication networks takes place.

Further features and advantages of the present invention will be described more in detail hereinbelow relating to a prefered embodiment of the process for the realization of attenuating elements for optical fibres with attenuating fibre according to the present invention and shown in the enclosed figures, in which:

- figure 1 shows a scheme of an attenuating optical fibre, joined at both ends to a standard monomodal fibre according to the realization process claimed by the present invention;
- figure 2 shows a scheme of an attenuating optical fibre, joined only at one end to a standard monomodal fibre, according to the realization process claimed by the present invention;
- figure 3 shows a scheme of an attenuating body comprising an attenuating optical fibre, joined at both ends to a standard fibre and to which a controlled stress has been applied, according to the realization process claimed by the present invention;
- figure 4 shows a scheme of an attenuating body comprising an attenuating optical fibre, joined at one end with a standard fibre and to which a controlled

stress has been applied, according to the realization process claimed by the present invention;

- figure 5 shows a scheme of an optical attenuating element with an attenuating fibre in the shape of a cord, according to the realization process claimed by the present invention;
- figure 6 shows a Cartesian diagram showing a plurality of attenuation curves according to the wave length and for different curving radius', induced onto a monomodal optical fibre with geometric and transmissive parameters typical of that fibre used in the attenuating element obtained by means of the process according to the present invention;
- figure 7 shows the scheme of a spectral attenuation diagram of an attenuating element with attenuating fibre realized by means of the process according to the present invention, without application of any particular stress to said fibre;
- figure 8 shows the scheme of a spectral attenuation diagram of an attenuating element with attenuating fibre realized by means of the process according to the present invention, with application of stress to the fibre.

Relating to the figures mentioned, 10 generically shows a standard monomodal fibre, 11 shows an attenuating fibre, 12 shows the fusion joints for joining fibres 10 and 11,

13 shows the rods of an attenuating body 18 which may also house fusion joints 12, 14 shows a central area of a portion of attenuating fibre 11 to which a bending is applied according to the process claimed by the present invention, while 15 shows a cord consisting of a portion of attenuating fibre 11, fusion joined to the standard monomodal optical fibre 10, and 16 shows two optical connectors possibly present at the ends of said cord 15. Furthermore, particularly relating to the Cartesian diagrams shown in figures 6-8, A shows, on the ordinate axis, a generic attenuation value in decibel (dB), while λ shows, on the abscissa, a generic value of wave length in micron (μm) and R the value of the different bending radius in millimetres (mm).

The process for the realization of attenuating elements for optical fibres with attenuating fibre according to the present invention mainly consists in placing an attenuating fibre 11, cut to an appropriate length, in such a way as to obtain the desired attenuation value.

The attenuating fibre 11 is obtained by means of doping with particular chemical substances like, e.g., transition elements or elements of rare earths for introducing into the silica transmission spectrum strong absorption bands which reduce the transmissibility of an amount increasing

together with the increasing of the entity of elements introduced in the vitreous matrix.

Furthermore, by opportunely proportioning the amount of introduced doping, it is possible to obtain a controlled attenuation of said fibre 11 with a low dependency on the wave length in the band interesting for telecommunications (1,26-1,58 μm).

The cut portion of attenuating fibre 11 will be fusion joined with a standard monomodal fibre 10 according to two possible shapes, respectively shown in figures 1 and 2.

In figure 1, the portion of attenuating fibre 11 is fusion joined at both ends to two portions of standard fibre 10, while in figure 2 said attenuating fibre 11 is fusion joined at one single end to a portion of standard fibre 10.

The joining parameters, like the current and the fusion time, permeation etc., relative to fusion joints 12, must be optimized so as to realize joints with very low leaks and however lower than 0,1 decibel, so as to minimize the modal interference, thus avoiding the use of expensive gorging of the power combined with upper modes.

The interference occurs when part of the power combined with the fundamental mode, excited on a section of said fibre 11, is converted again into the power relative to the fundamental mode, in correspondence to a following attenuating section near to the precedent one and however such, that the difference in optical run between the two modes is lower than the coherence length of the light source.

The following oscillating effect of the spectral attenuation is as sharp as the attenuation of the attenuation sections is high.

At the end of the joining operation, said fibres 10 and 11 are inserted and fixed inside an attenuating body 18 containing rods 13, and that may house also fusion joints 12.

Now said body 18 is lapped on both sides according to conventional techniques used for optical connectors, and assembled in the outer body of attenuating elements, the most common shapes seem to be those compatible with connectors SC, FC or ST.

As an alternative, the attenuating fibre 11 may be joined on both sides to two long portions of standard fibre 10, in the above described manner, and protected by a special

tube in turn contained in the protection cord 15, as shown in figure 5.

Now a controlled stress is introduced in correspondence with a central area 14 of the portion of attenuating fibre 11 or of standard monomodal fibre 10, with the purpose of improving the spectral response of the attenuating element to wave lengths greater than 1,58 μm, and in particular to wave lengths comprised between 1,58μm and 1,65 μm.

The controlled stress consists of the application of a light bending of the optical fibre 10, 11, which causes an increase of the attenuation at the high wave lengths, thus counterbalancing the rough decrease of the spectral attenuation of attenuating fibre 11 in this area.

And this allows to make the spectral response of the attenuating element further flat also towards greater wave legths, i.e. those usually corresponding to the monitoring values of the telecommunication networks.

Infact, if α is the attenuation for the unit of length of the attenuating fibre, α_{g1} and α_{g2} the attenuation of the two joints (where one single joint exists, only one of the two contribution exists) and α_{c1} and α_{c2} are the attenuation of two connections, the attenuation provided by the attenuating

element - exepted the contribution of the bending in area 14 and overlooking the attenuation of the standard monomodal fibre 10 - is the following:

$A = \alpha 1 + \alpha_{s_1} + \alpha_{s_2} + \alpha_{c_1}$ and α_{c_2} (in dB),

where 1 is the length of the portion of attenuating fibre.

Further, it is shown that the attenuation value A_b introduced by the bending in said area 14, if present, is given by the following expression:

$$A_b = 4{,}34\left\{ 2\,(a/R)^2\,(r_o/a)^6\,(V^4/8\Delta^2) + \left[(\pi^{1/2}/2a)\,(a/R)^{1/2}\,(V^2W^{1/2}/U^2)\,e^{-4RW^3\Delta/3aV^2}\right]\pi R\right\}[\mathrm{dB}]$$

where a shows the radius of the core of the optical fibre, r_o is the radius of the modal field, R is the bending radius - presumed constant - Δ the numeric opening, V the normalized frequency, U the normalized phase parameter and $W = (V^2 - U^2)^{1/2}$.

From figure 6, where the diagram of attenuation A is shown when the wave length λ varies due to different bending radius' R, it is possible to note that with bending radius R equal to about 2,5 mm, an increase of attenuation A of about 1 dB may be obtained to the wave length λ of 1,6 μm, while the same increase of attenuation introduces a small and relatively constant attenuation A to the low

wave lengths λ , which may be taken into account in the dimensioning phase of said attenuating fibre 11.

Figures 7 and 8 show the spectral attenuation curves of an attenuating element with an attenuating value of 20 decibel, respectively before and after having induced the bending in the area 14 of the portion of fibre 11 or 10. By comparing the two figures, it is possible to note the straightening effect of the bending in the area 14 onto he spectral feature of the high wave lengths λ .

The features of the process for the realization of attenuating elements for optical fibres with attenuating fibres according to the present invention are clear from above specification, as well as the following advantages.

In particular, said advantages are shown by the fact that, unlike the conventional techniques for the realization of all-fibre attenuating elements with a spectral response independent from the wave length, usually based onto the deformation of an optical fibre, the technique described in the present specification allows to obtain a low interference between the fundamental mode and the first upper mode of the fibres, as the power lost by the fundamental mode is absorbed by the amorphous structure of glass and transformed into heat, while only a small

part is transferred to the upper modes in correspondence of the joints and of the connectors.

On the other hand, it must be reminded that the power conversion between the fundamental mode and the upper modes - which is responsibile for the arising of modal interference - is the mechanism that generates attenuation on the attenuating elements with deformed fibre.

Furthermore, the attenuating element directly obtained by means of the realization process according to the present invention, allows to work also in the wave length space of values from 1,58 μm to 1,65 μm, where usually the telecommunication network monitoring is performed. At last, the width of the oscillations in the spectral response, following to model interference, is substantially independent from the leaks of the connections.

It is evident that many variants may be brought, by the person skilled in the art, to the process for the realization of attenuating elements for optical fibres with attenuating fibre according to the present invention, without therefore leaving the protection limits of the novelty, as well as it is evident that in the realization of the invention the shapes, in the details described, may be different and the same may be replaced with technically equivalent elements.

Due to the low modal interference, e.g., the attenuating element with attenuating fibre obtained by means of the realization process described may be placed directly in front of a light tracer, so as to supply an attenuation value similar to the one shown by the same component when it is placed between two monomodal fibres.

Vice versa, the conventional attenuating elements show a high modal interference and when they are directly connected in front of the receiver they show an attenuation much lower than the one measured between two monomodal fibres, as the power combined to upper modes running in the shell is captured by the light tracer and is not filtered as it would occur if the attenuating element was followed by a monomodal fibre.

CLAIMS

1. A process for the realization of attenuating elements for optical fibres with attenuating fibre, of the compact kind, *characterized in that* it comprises the following phases:
   - the cut of a portion of attenuating fibre (11) of suitable length, such as to obtain a desired attenuation value, and fusion joint in at least one point of said portion of attenuating fibre (11) with at least one portion of standard monomodal optical fibre (10), so as to realize at least one fusion joint (12) with leaks lower than 0,1 dB, so as to minimize the modal interference;
   - the insertion and fixing of the fibre thus obtained inside an attenuating body (18), containing a plurality of rods (13) that also may house said fusion joint (12);
   - the lapping of said attenuating body (18) on both sides, according to conventional techniques;
   - the assemblying of said attenuating body (18) in the outer body of an optical attenuating element, called optical attenuating element as it is compatible with optical connectors (16), like e.g. SC, FC, ST;

   whereby said attenuating fibre (11) consists of an optical fibre doped with suitable quantities of chemical substances, like iones of transition elements and/or elements of rare earths, so as to obtain a spectral attenuation of said attenuated fibre (11) substantially controlled and uni-

form, at least inside the wave length space of values (λ) 1,2-1,7 μm (included extreme values).

2. A process for the realization of attenuating elements according to claim 1, *characterized in that* it provides the following further phase, successive to said jointing operation:
   - the protection of said attenuated fibre (11) and of said fusion joints (12) by means of two standard monomodal optical fibres (10) in a suitable tube in turn contained inside a small protection cable or cord (15), possibly connected to optical connectors (16), like e.g. SC, FC, ST.

3. A process for the realization of attenuating elements according to claim 1, *characterized in that* it provides the following further phase, successive to said jointing operation:
   - the manipulation and/or deformation of at least one portion of said attenuating fibre (11), or of said standard monomodal optical fibre (10), by the application of a light bending produced in a central area (14) of said portion of attenuating fibre (11) or standard optical fibre (10), which brings along an increase of attenuation (A) of said optical attenuating element to wave length values (λ) substantially higher than 1,5 μm with respect to optical attenuating ele-

ments comprising not bent portions of attenuated fibre (11) or of standard optical fibre (10), whereby in particular said attenuation increase (A) results in about 1 dB for each wave length (λ) equal to about 1,6 μm for bending radius' (R) of about 2,5 mm.

4. An attenuating element for optical fibres with attenuating fibre, of the compact kind, *characterized in that* it comprises at least one portion of attenuating fibre (11) of suitable length, such as to obtain a desired attenuation value, whereby said portion of attenuating fibre (11) is connected, in at least one point, with at least one portion of a standard monomodal optical fibre (10), so as to realize at least one fusion joint (12), with leaks lower than 0,1 dB, with the purpose of minimizing the modal interference, and the fibre thus obtained is inserted and fixed inside an attenuating body (18), containing a plurality of rods (13), which may also house said fusion joint (12), whereby said attenuating body (18) is lapped on both sides, according to conventional techniques, and assembled in the outer body of said optical attenuating element, and said optical attenuating element is compatible with optical connectors (16) like e.g. SC, FC, ST.

5. An attenuating element for optical fibres according to claim 4, *characterized in that* said attenuating fibre (11)

consists of an optical fibre doped with suitable quantities of chemical substances, like iones of transition elements and/or rare earths elements, so as to obtain a spectral attenuation of said attenuating fibre (11) substantially controlled and uniform, at least inside the wave length space of values (λ) 1,2-1,7 μm (included extreme values).

6. An attenuating element for optical fibres according to claim 4, *characterized in that* said portion of attenuating fibre (11) with the relative joints (12) with standard monomodal fibre (10), is protected inside a suitable tube in turn contained inside a small protection cable or cord (15), possibly connected to optical connectors (16), like e.g. SC, FC, ST.

7. An attenuating element for optical fibres according to claim 4, *characterized in that* said portion of attenuating fibre (11) or standard monomodal optical fibre (10) is lightly bent in a central area (14), so as to bring along an attenuation increase (A) of said optical attenuating element to wave length values (λ) substantially greater than 1,5 μm with respect to optical attenuating elements comprising not bent portions of attenuated fibre (11) or of standard optical fibre (10), whereby said attenuation increase (A) particularly results in about 1 dB for each wave length (λ), equal to about 1,6 μm for bending radius' (R) of about 2,5 mm.

8. An attenuating element for optical fibres according to claim 4, *characterized in that* it is placed directly in front of at least one light tracer, thus supplying an attenuation value (A) similar to the one shown by said light tracer when it is placed between two monomodal fibres.

9. An attenuating element for optical fibres according to claim 4, *characterized in that* it is used in at least one interval of those wave lengths corresponding to those where usually the monitoring of telecommunication networks takes place.

10. A process for the realization of attenuating elements for optical fibres with attenuated fibre, and attenuating element thus obtained, mainly as described and shown in the enclosed drawings.

Fig.1

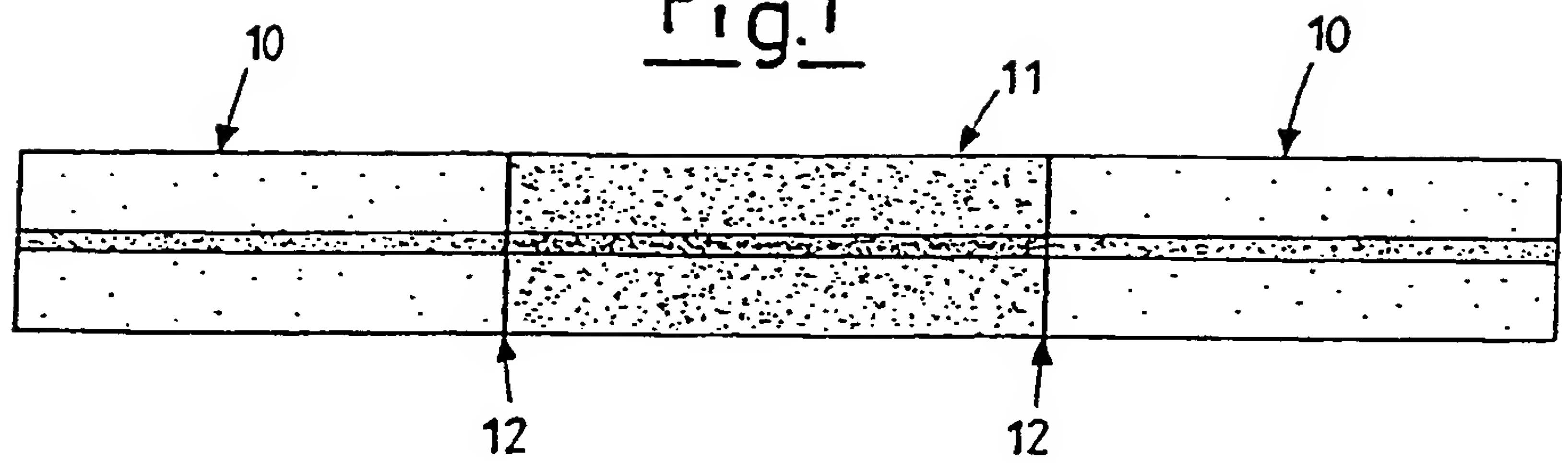


Fig.2

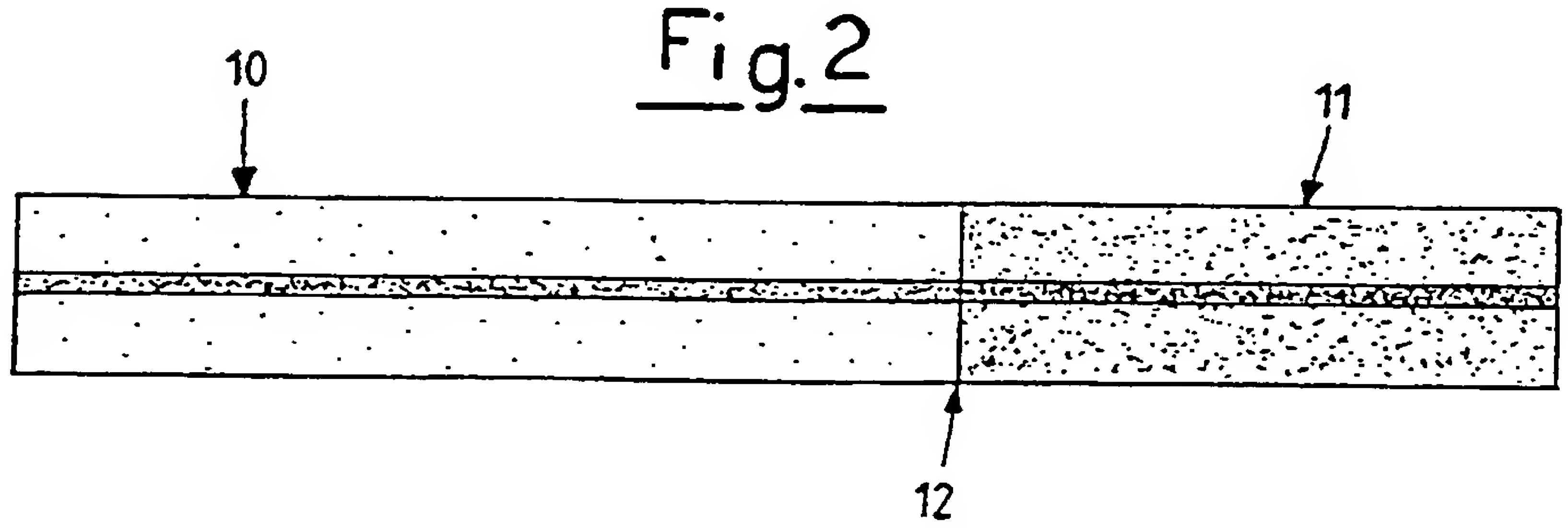


Fig.3

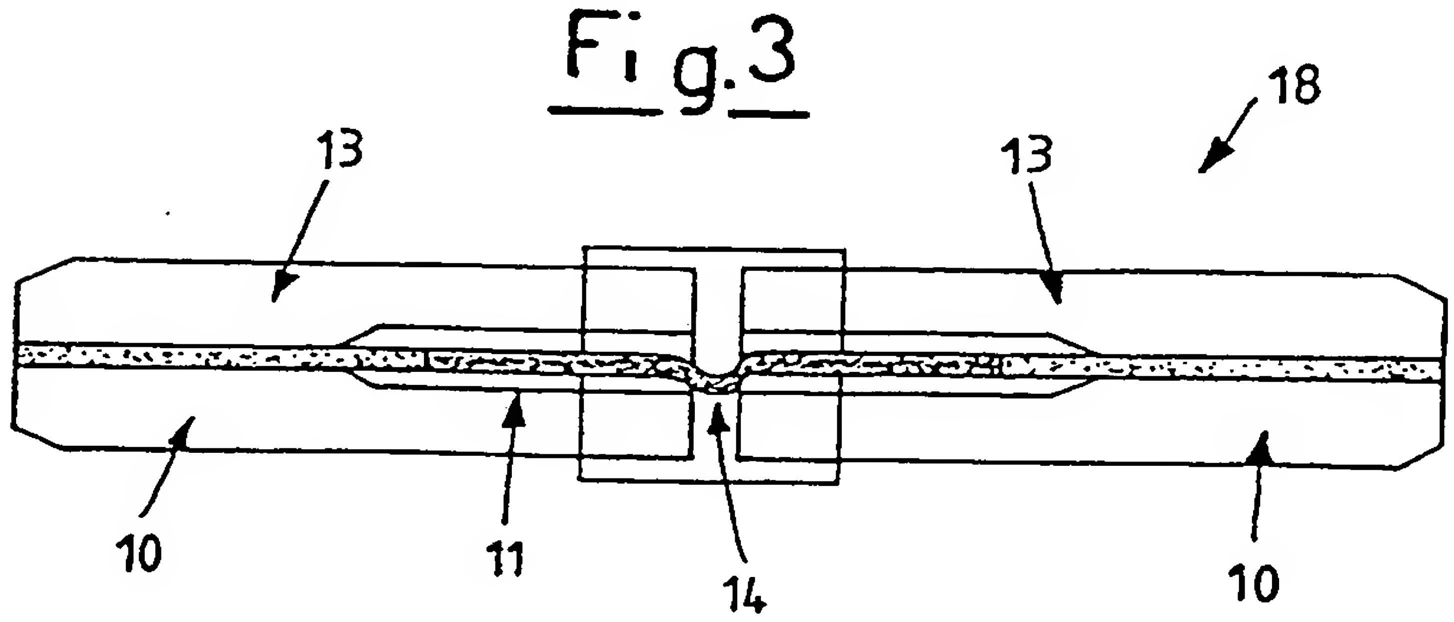


Fig. 4

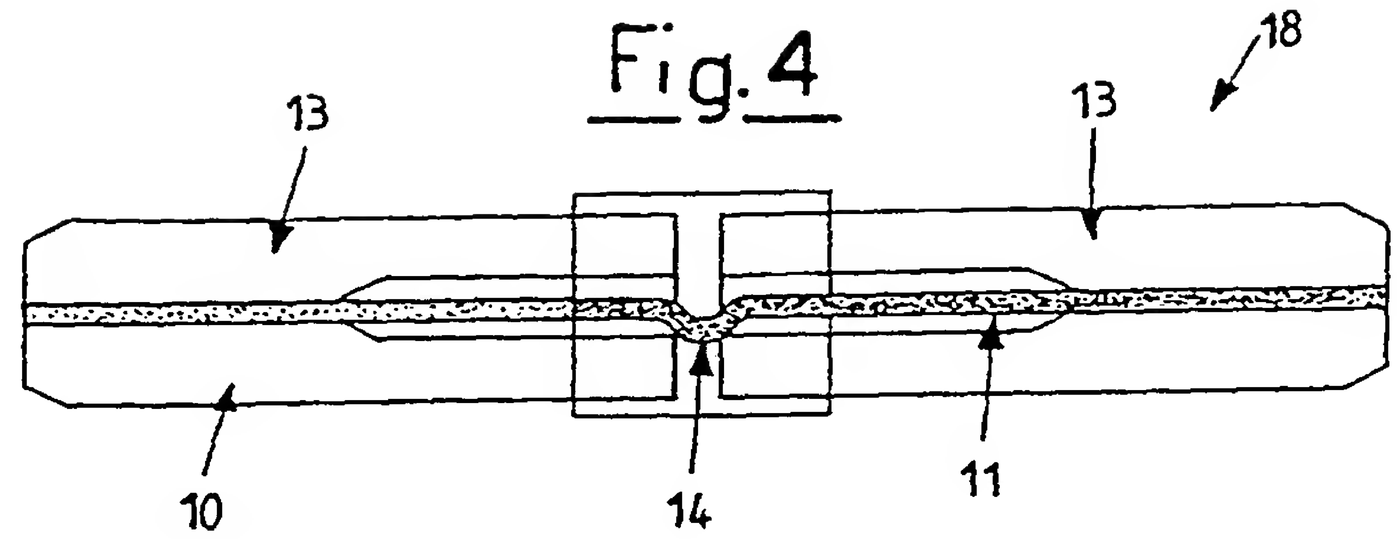


Fig. 5

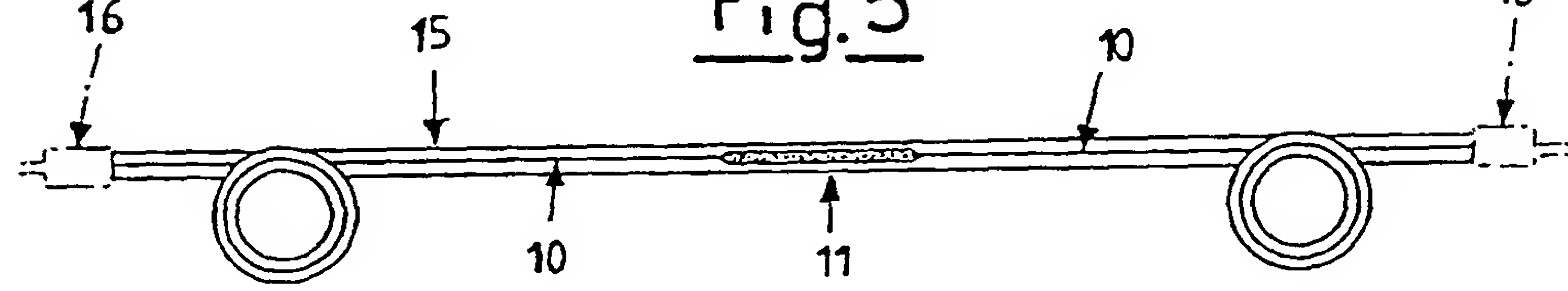


Fig. 6

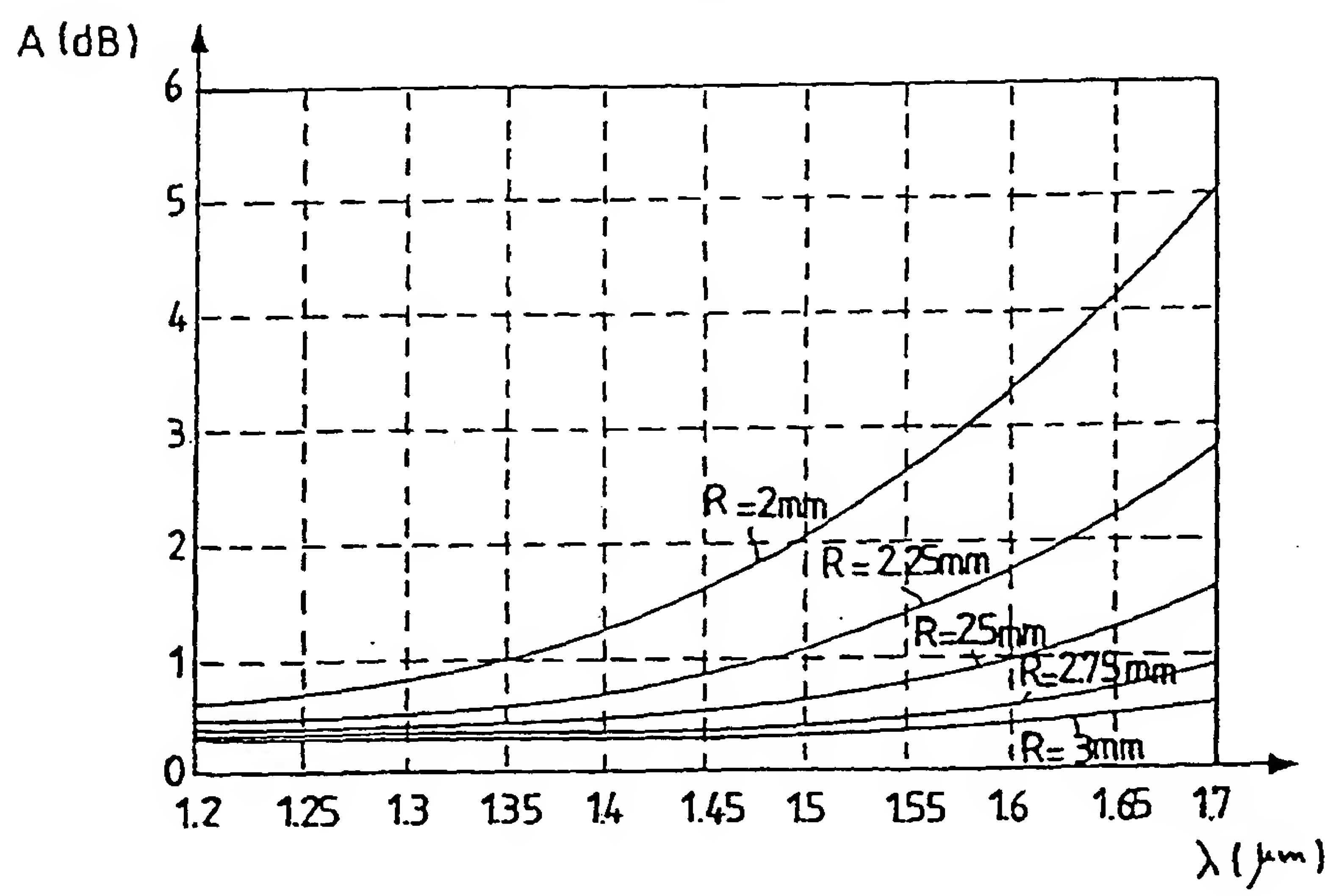


Fig.7

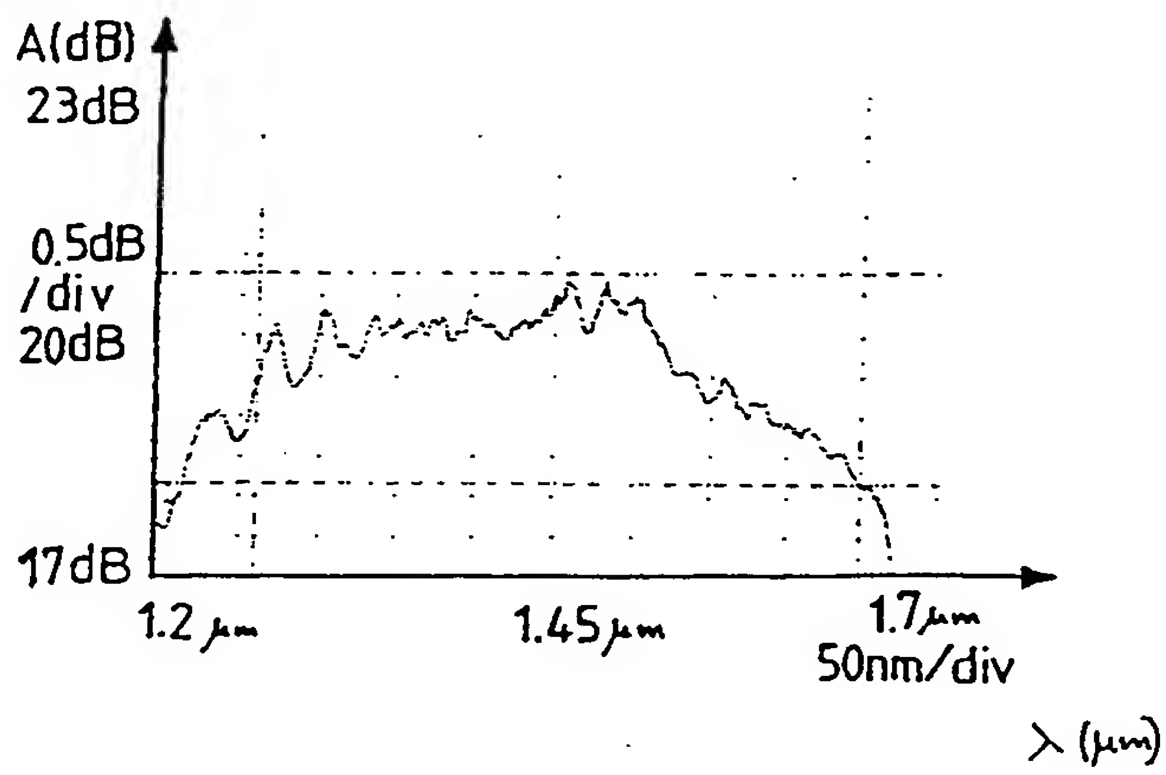
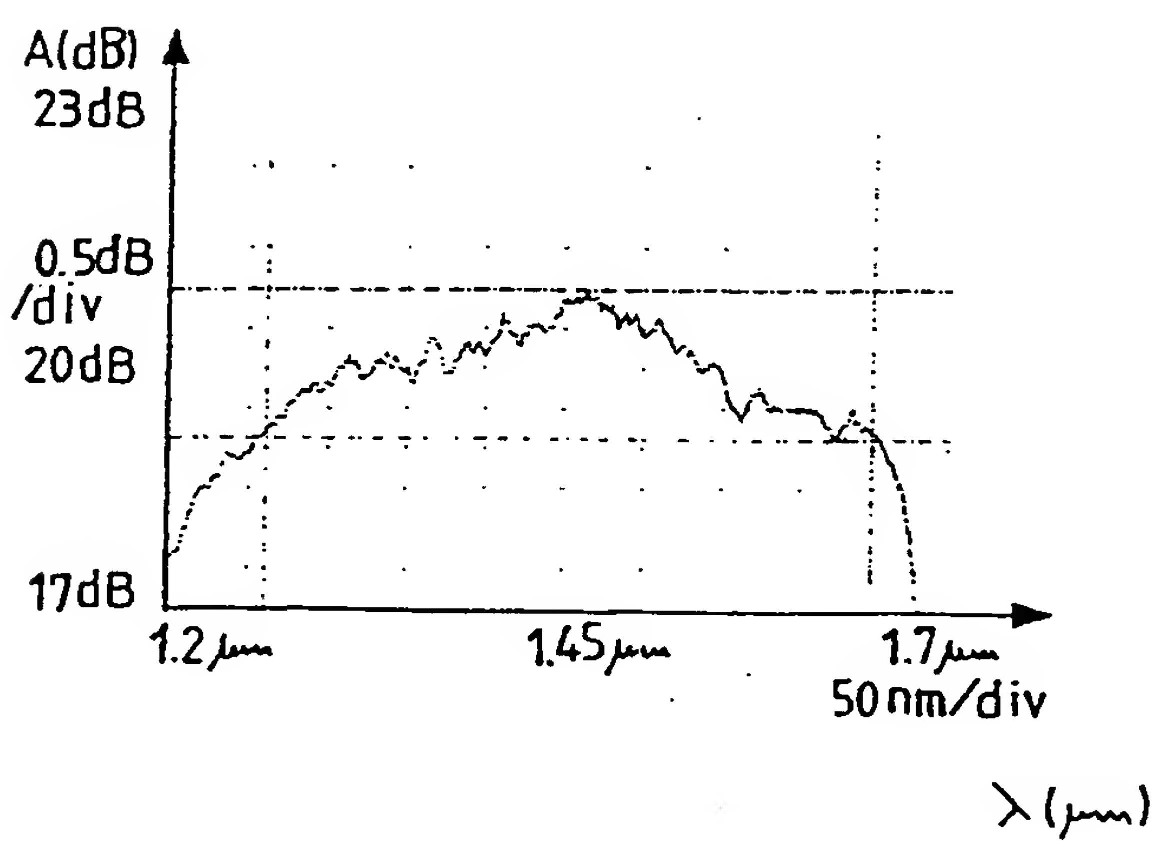

A(dB)
23dB
0.5dB
/div
20dB
17dB
1.2 µm
1.45 µm
1.7 µm
50nm/div
λ (µm)

Fig.8


A(dB)
23dB
0.5dB
/div
20dB
17dB
1.2 µm
1.45 µm
1.7 µm
50 nm/div
λ (µm)

INTERNATIONAL SEARCH REPORT

Inte· ›nal Application No
PCT/IT 98/00207

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B6/26 G02B6/38

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y A	PATENT ABSTRACTS OF JAPAN vol. 096, no. 009, 30 September 1996 -& JP 08 136735 A (SHOWA ELECTRIC WIRE &CABLE CO LTD; NIPPON TELEGR & TELEPH CORP), 31 May 1996 see abstract ---	3,7 1,9
X A	US 5 109 468 A (TAMULEVICH THOMAS W ET AL) 28 April 1992 see column 3, line 40 - line 44 see column 4, line 17 - line 50 see column 2, line 31 - line 34 ---	4,6,9 1,2

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 November 1998	12/11/1998

Name and mailing address of the ISA	Authorized officer
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

International Application No
PCT/IT 98/00207

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